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WATER QUALITY CHANGES DURING DISTRIBUTION

REPORT #81

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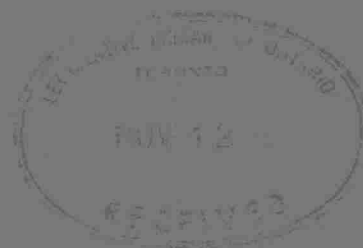


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WATER QUALITY CHANGES DURING
DISTRIBUTION

(Report # 81)

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ABSTRACT

There were six (6) plants and distribution systems studied. No significant changes occurred in the chemical parameters studied. The total count did not correlate with the occurrence of coliforms, other indicators or the amount or type of chlorine residual. There was no significant correlation between temperature and total bacterial count, although temperatures in the distribution systems surpassed those at which bacterial multiplication would be expected to occur. The presence/absence test was found more sensitive than the membrane filter test for coliform detection.

INTRODUCTION

Potable water quality can be defined in terms of both microbiological and chemical parameters. Drinking water is not permitted to contain impurities that may be hazardous to health. To this end, limits (or in certain instances objectives) have been set on the values of most chemical and microbiological constituents of water by the controlling agency (1). These limits apply at the consumer's tap, not merely in the treated water as it leaves the plant.

It is generally agreed that water in the distribution system will not exceed in quality that of the finished water at the point of production. Chemical reactions can occur between the water and the various materials making up the distribution system. Additionally, full water treatment with disinfection is not expected to produce a sterile water; some microorganisms will survive, enter the distribution system and react with the chemical components in the water and those of the distribution system. The net result in many cases is growth of the microorganisms, resulting in chemical changes in the water and the piping of the system, and deterioration in the bacterial and chemical quality of the water.

The quality of the delivered water will depend not only on that of the source water and the treatment applied to it, but also on the condition and design of the distribution system and various operation and maintenance practices (2).

Considerable emphasis by way of research and development has always been placed on the treatment phase of water supply and its effect on public health; there is an equal need for emphasis in the operation and maintenance of distribution systems (3).

The interior surface of a distribution system (1 km of 15.0 cm main provides about 471 square metres of surface area) offers vast opportunities for physical, biological and chemical reactions to occur; the surface area relative to flow is greater in the smaller mains, where more acute quality changes would therefore be expected to occur.

Many species of bacteria, including *Pseudomonas*, *Achromobacter*, *Aerobacter* and *Crenothrix* species, are able to grow in water of unquestionable potable quality, and some even in distilled water (4). These bacteria are not normally regarded as pathogenic, but some are "opportunistic pathogens" capable of causing serious secondary infections for debilitated members of the community, such as the very old, the very young, surgical and burn patients etc. Growth of these microorganisms creates potentially hazardous conditions in the water, which will not necessarily be detected by the standard coliform test; in fact, their presence may mask that of the coliforms, which may be present also in the system (5).

The bacteria which grow are usually representative of those in the original water source, which have survived disinfection and reverted to growth under favourable conditions. They may grow on materials remaining in the water after treatment or on non-metallic materials present in the system (6). These materials, such as paints, coatings, gland packings, lubricants, sealants, plastics (PVC, ABS etc.) and many others are used for many purposes within the piping network. Aerobic bacteria require carbon, nitrogen, oxygen and some mineral salts for active multiplication and carbon is nearly always the limiting factor in preventing growth in good quality potable waters. Non-metallic materials can donate sufficient carbon to the system to facilitate microbial growth. Such growth may cause physical deterioration in the material involved, leading to failure in its function.

Other sources of material and microorganisms entering lines are cross-connections, main breakages and repairs and new connections (7). Such sources may introduce pathogenic microorganisms into the supply. It is worth noting that distribution system deficiencies (cross-connections, repairs and inadequate disinfection of new mains) were shown to be responsible for the majority of disease outbreaks in municipal water systems, during a survey of waterborne illness (3).

The growth of bacteria in a distribution system may result in any or all of the following effects:-

- a) The disappearance of the chlorine residual,
- b) Reduced pipeline capacity,
- c) Tastes and odours,
- d) Sloughing of slime from the mains,
- e) Increases in the total bacterial count, which may or may not be accompanied by the appearance of total coliform or other indicator bacteria,
- f) Changes in the chemical characteristics of the water eg. an increase in the concentration of iron.

Chemical changes such as corrosion processes are known to occur, and the deposition and resolution of water minerals in pipelines is a well-recognized phenomenon. The factors that control these processes, which cause changes in water quality in the distribution system, are not however well-defined. It might be predicted, for example, that certain changes in water quality would occur as the temperature of the water in the mains increases in late summer, but other predisposing conditions must be present to result in deterioration.

This study was designed to detect water quality changes in several distribution systems and determine the relationships with such factors as raw water quality, chlorine residual and chemical composition. Data were collected from six different water treatment plants and distribution systems, with sampling at approximately weekly intervals over a period of a little more than two and one half years.

The plants and distribution systems studied were selected on the basis of the type of raw water source, the size and characteristics of the distribution system and the method of treatment applied. All were readily accessible and at a distance from the analytical laboratory such that samples could be processed on the day of collection.

DISTRIBUTION SYSTEMS

The water plants and distribution systems included in the study are shown in Table 1.

TABLE 1
WATER PLANTS AND
DISTRIBUTION SYSTEMS STUDIED

Plant	Source	Type of Treatment	Disinfection Method
A	Lake Ontario	Full treatment	Chlorine gas
B	Lake Ontario	Full treatment	Chlorine gas
C	Lake Ontario	Full treatment and transmission line	Chlorine gas
D	Well	Filtration	Chlorine gas
E	Well	Filtration	Chlorine gas
F	Well	None	Hypochlorite solution

There were three plants treating water from Lake Ontario (A, B and C); these plants employed a full treatment regime of pre-chlorination, settling, coagulation, filtration and free residual post-chlorination before distribution. For plants A and B, raw and finished water samples were taken at the plant on a weekly basis along with two samples from each distribution system. Both plants initially distributed water containing a free chlorine residual; approximately halfway through the study Plant B used free residual post-chlorination for disinfection, but then ammoniated to yield a combined residual before pumping the water to distribution. No chlorine booster stations were in operation during the study.

In the case of C, the sampling points were selected so as to determine the effect of a long transmission line on water quality. From plant C, water is pumped about 8.5 km to a covered reservoir; booster pumps then propel the water 10.5 km to another covered reservoir. Booster pumps feed the distribution system from this reservoir. The pipeline consists of concrete-lined steel and varies in size from 1.52 m diameter to 1.07 m diameter along its total length of approximately 19 km. Three sampling points were established at increasing distances from the point of discharge of the pipeline into the distribution system. No booster stations for chlorine addition were in use on this system.

Three plants utilizing ground water were studied. Plants D and E are similar in that they both treat ground water by filtration and chlorination. At D the chlorine is applied in a contact chamber prior to filtration through vertical anthracite filters, employed primarily for iron removal. There is a water tower on the system approximately 2.5 km from the treatment plant, discharging when required, and there are no chlorine booster stations. At the time of the study, plant E pumped ground water from several wells through a horizontal anthracite filter, after which chlorine and sodium silicate for iron sequestering were added and the water entered a storage reservoir at the plant. On occasions of heavy water demand, supplied water may have entered the system directly, by-passing the storage reservoir; a further storage reservoir was available to the system some 3.5 km from the treatment plant. Samples of raw and treated water were taken at the respective plants, as well as two samples from each distribution system.

At plant F, hypochlorite solution is administered to the water as it passes into the main at the pump-house, whence the water is pumped to the distribution system; on demand, the water is released from a stand pipe on the system, with pumping from the well resuming when the distribution system pressure drops to a pre-set level. There is therefore no chlorine contact basin. Sodium silicate is used for iron sequestering and is added directly to the water as it passes to the main from the pump. Samples were taken of the raw and treated water at the pump-house, and at two other locations in the distribution system; one was located about 2.5 km from the pump-house, and the other at the end of an old, long main about 5.5 km from the pump-house.

The distances of the various sampling points from the water plants are summarized in Table 2.

MATERIALS AND METHODS

A. CHEMICAL

(1) Sampling - Two water samples were collected at each sampling point after allowing the tap to run for 2 minutes, in standard chemical sampling bottles. The temperature of the water

TABLE 2
DISTRIBUTION SYSTEM SAMPLING POINTS

PLANT	Distance in km from Plant		
	*DS 1	DS 2	DS 3
A	2.25	9	-
B	3	8	-
C	19.8 ⁺	22.9	24
D	1.4	2.5	-
E	1.8	3	-
F	2.5	5.5	-

+ - transmission line

* - DS = distribution sample

was taken at the time of sampling, with a standard laboratory thermometer. Total and free chlorine residuals were also determined at the time of sampling, using the DPD comparator method (8).

(2) Analysis - The analyses carried out on each water sample, using standard methods employed by the Ministry of the Environment laboratories (9) were as follows: - pH, turbidity, colour, suspended solids, hardness, alkalinity, iron, manganese, ammonia, Kjeldahl-nitrogen, nitrate, nitrite, chloride, phenol, sulphate, TOC and BOD.

B. BACTERIOLOGICAL

(1) Sampling - Water samples were collected using aseptic techniques into sterile bacteriological sample bottles; samples of treated water were taken in bottles containing sufficient sodium thiosulphate to destroy any chlorine residual. The samples were analyzed, usually within three hours of collection and always on the day of collection.

(2) Analysis - Bacteriological analyses were carried out using several standard techniques:

a) Membrane Filter Procedure - The membrane filter (MF) test for total coliforms was carried out according to the method outlined in Standard Methods (10) using m-Endo broth (Difco). Doubtful colonies were confirmed by inoculating a small amount to EC broth and incubating at 35° C for 24 to 48 hours; the production of gas confirms the colony as a coliform.

b) Presence/Absence Procedure - The presence/absence (P/A) test (11) can be used to detect the presence of total and fecal coliforms as well as other indicators of water quality, such as fecal streptococci, fluorescent pseudomonads and Clostridia. Following the outlined procedure, coliforms, fecal coliforms, fecal streptococci and Clostridium organisms were identified; organisms exhibiting anaerogenic coliform and aeromonas reactions were designated "atypical coliforms" and their identification was not further pursued. Organisms exhibiting fluorescence in Drakes medium were identified as "fluorescent pseudomonads". No analysis was done for Staphylococcus.

c) Total Plate Count - Counts for total bacteria were performed according to the methods outlined in Standard Methods (10) using two 1 ml and two 0.1 ml aliquots from each sample and using plate count agar (Difco). After incubation for 48 hours at 35° C the counts were made with the aid of a Quebec colony counter.

RESULTS AND DISCUSSION

The data collected in this study were subjected to regression analysis, to determine whether, for each individual system studied, changes occurring in any specific parameter could be correlated with variations in any other; only correlations at the 95% level of significance were accepted.

Additionally, changes in bacterial or chemical quality were examined to reveal the extent, if any, of deterioration in water quality within each system.

CHEMICAL

Few well-defined, consistent relationships were determined. Only chloride concentrations correlated significantly at the 95% level with those of both sulphate and nitrate in the finished and distribution system waters. There was no evidence in any system that the chemical quality of the water consistently deteriorated with increasing distance from the plant. Average iron concentrations decreased marginally through the system, if present in the finished water at levels in excess of 0.5 mg/L, indicating a tendency to deposit in the mains; marginal increases in average iron concentration were detected if starting levels were below 0.05 mg/L.

The chlorine data showed that all but two of the systems studied (plants C and F), had little difficulty in maintaining an average total residual of at least 0.2 to 0.3 mg/L as far as the final sampling point. Table 3 shows the average chlorine residuals for the year 1975.

TABLE 3

DECAY OF CHLORINE RESIDUAL THROUGH THE DISTRIBUTION SYSTEM

Plant	Residual Type	Average yearly Chlorine Residual (mg/L) 1975		
		Finished	DS 1	DS 2
A	Total	0.4	0.3	0.2
	Free	0.22	0.1	0.01
B	Total	0.5	0.5	0.5
	Free	0.2	0.1	0.1
C	Total	0.41	0.07	0.06
	Free	0.1	0.01	0.01
D	Total	0.5	0.35	0.34
	Free	0.2	0.04	0.09
E	Total	0.5	0.4	0.4
	Free	0.2	0.2	0.2
F	Total	0.22	0.3	0.03
	Free	0.1	0.1	0.01

* Chlorine applied as hypochlorite solution; solution may not have been completely mixed with the water when 'finished' water sample was taken by virtue of the manner of addition.

For plant C, where the finished water enters the distribution system at the end of a long transmission line, although an average total residual of about 0.4 mg/L could be measured leaving the plant, total chlorine residual in the sample closest to the point of discharge into the system was never greater than 0.3 mg/L (average 0.07 mg/L) and at the subsequent point was less (average 0.06 mg/L). The "stale" residual present at the end of the transmission line (12) did not penetrate far into the system. It is probable that the installation of a chlorine booster station at the point of discharge from the pipeline into the system, would aid in the maintenance of a total chlorine residual in the distribution system. At plant F, where hypochlorite solution was the source of chlorine, a chlorine residual could seldom be measured at the sampling point furthest from the plant, probably because of fouling in the main.

Chlorine residual measurements were essentially similar for the other years of the study except for plant B, where no free chlorine residual could be demonstrated in the distribution system following the change in disinfection practice.

BACTERIOLOGICAL

The P/A test was shown, as before (11), to be more sensitive than the MF for the detection of coliform bacteria in treated drinking water; 2.2% of the total samples were confirmed positive for total coliforms when the MF gave negative results, whereas only 0.8% of the total samples were confirmed by MF when the P/A test was negative for coliforms. The P/A test is used routinely in the Ministry of the Environment laboratories for the analysis of treated drinking water samples.

Deterioration of bacterial quality in the distribution system is one of the greatest concerns of water suppliers. Plate counts

have been recommended (5) as a routine procedure to detect this deterioration, as well as to warn of potential situations where the detection of coliforms could be masked, and as a practical measurement of the attainment of population control by chlorine. Although certain industrial water users require a plate count of less than 50 organisms per ml (13), in their process water, a level of 500 organisms per ml has been suggested as a maximum for distributed potable water (14,15).

It has been reported (16) that a substantial increase in total chlorine residual to about 1.5 mg/L was required to improve the quality of the water with respect to coliforms, over that which existed when a 0.2 mg/L total residual was maintained. However, studies in the United States (5), on over 900 water systems of all types, have indicated that the total bacterial population in the distribution system can be controlled below 500 organisms per ml in most cases (87.3%), by maintaining a total chlorine residual of about 0.3 mg/L; a further increase in chlorine level produced no significant decrease in the microbial population.

Total counts in the distribution systems in this study, did not often exceed 300 organisms per ml, and most systems maintained an average level below 50 organisms per ml. The presence or absence of total coliforms or any other indicator did not appear to correlate with the magnitude of the total count, although there were insufficient indicator recoveries to permit significant statistical analysis.

Also, no correlation was found to exist between the size of the total plate count and the amount of either the free or the combined chlorine residual. This result tends to agree with those obtained with an experimental pipeline (17), where a free residual of 0.6 to 1 mg/L, exhibited no advantage over a combined residual of the same magnitude provided the chlorine dosage had not been allowed to lapse. This phenomenon was also shown for Plant B, where no deterioration was found in bacterial quality (as measured by total

count) after the plant changed from free residual chlorination to ammoniation of the residual partway through the study; the distribution system appeared to be as well protected by the presence of a 0.4 to 0.5 mg/L combined residual as it had been by a 0.1 to 0.2 mg/L free residual.

Even where a chlorine residual could seldom be detected (sampling point 2, Plant F), the total counts obtained were of the same order of magnitude as those at sampling point 1, where a free chlorine residual was often found. Chlorine residuals in general tended to be lower in the distribution systems in the summer period (with the exception of Plant F), but little significant increase in bacterial numbers occurred.

It would be expected that total plate counts could be affected by temperature changes in the distribution system. Increases in total counts have been reported to occur (7) in distribution systems in August, September and October when water temperatures in the pipelines increase. A critical temperature of 12-13° C has been suggested (18), above which active bacterial multiplication would be expected to occur; chlorine residuals become more reactive up to 18-19° C, but then residual depletion increases much more rapidly (19). Whether or not bacterial multiplication proceeds at elevated water temperatures, would therefore be expected to depend on local conditions of chlorine residual, availability of nutrients, etc.

Temperatures in the distribution systems did reach as high as 23° C on occasion. Average summer temperatures were usually in excess of 14.5° C, where bacterial multiplication should progress, whereas average winter temperatures were generally below 12° C, as shown in Table 4.

TABLE 4

AVERAGE TEMPERATURES IN DISTRIBUTION
SYSTEM WATER (1975)

Plant	TEMPERATURE °C			
	Summer (May-October)		Winter (Nov.-April)	
	DS(1)	DS(2)	DS(1)	DS(2)
A	15.9	16.7	10.6	11.8
B	16.2	14.7	11.4	11.3
C	15.0	16.0	10.9	12.2
D	14.4	14.7	12.2	13.0
E	12.9	13.7	12.4	12.3
F	14.6	15.3	10.3	11.0

However, regression analysis of the entire data set showed only a slight correlation between temperatures and total count, only in the case of Plants C and F. The reasons for this apparent anomaly were not known.

CONCLUSIONS

In the distribution systems studied, there was no significant change in the chemical parameters measured.

Although chlorine residuals decreased as the water passed through the distribution systems, all but two plants could maintain an average total chlorine residual of 0.3 mg/L or greater well into the system.

The P/A test was more sensitive than the MF test for the detection of coliforms; coliform indicator bacteria were found on rare occasions in all of the distribution systems, but the quality of the water was always well within the limits set out in the drinking water objectives of the Ministry of the Environment. The total count did not correlate with the occurrence of coliforms or other indicators or with the amount or type of chlorine residual present.

Temperatures in the distribution systems studied surpassed levels at which bacterial multiplication would be expected to occur, but no significant correlation between temperature and total count was found.

There were therefore, few conclusions that could be drawn from this study. It is possible that a different study design, such as a more detailed survey of only one system, would have yielded more information. Bacterial multiplication and chemical change within distribution systems depend on so many inter-relating factors, that it may not be possible to elucidate them, other than by using an experimental system, where all the factors can be controlled.

Note: The raw data from this study is on file with the Water Technology Section; the amount (400-500 pages) precludes its inclusion in this report.

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